

Distribution patterns of deep-sea benthopelagic fish off the Algarve coast (Portugal)

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ABSTRACT

The present study characterises and compares the structure and diversity of the deep-sea benthopelagic ichthyofauna off the southern Portuguese coast, according to the biomass values –in kg/(nautical mile)²– of ten teleost and seven chondrichthyan species.

The differences between the biomass of benthopelagic species were assessed by depth interval and sampling season. It seems clear that even at 100 m depth intervals there are differences within the fish assemblages, and that a few species make most of the contribution to such differences. No traces of seasonality or even differences between the sampling years have been found. There is a separation between slope habitats from 400-700 m depth and deeper ones, determined by a change in fish communities.

Keywords: Benthopelagic, ichthyofauna, Algarve, Portugal.

RESUMEN

Patrón de distribución de peces nectobentónicos del talud continental a lo largo de la costa del Algarve (Portugal)

Se han caracterizado y comparado la estructura y la diversidad de la ictiofauna nectobentónica de los fondos oceánicos de la costa sur de Portugal a partir de los valores de biomasa –en kg/(milla náutica)²– de diez especies de teleósteos y siete especies de condricios.

Las diferencias de biomasa entre las distintas especies nectobentónicas encontradas fueron determinadas por intervalos de profundidad y épocas de muestreo. Los resultados vienen a demostrar que, incluso por intervalos de profundidad de 100 m, hay diferencias significativas entre las comunidades de peces, y que hay algunas especies que contribuyen en la mayoría de estas diferencias. Sin embargo, no se pudo encontrar ninguna diferencia significativa entre épocas y tampoco entre los años de muestreo. Existe una separación entre los tipos de habitat del talud entre 400-700 m de profundidad y otros situados en zonas más profundas, resultado de un cambio en las comunidades piscícolas.

Palabras clave: Demersal, ictiofauna, Algarve, Portugal.

INTRODUCTION

Stock depletion is most likely to drive fishing efforts off the shelves towards the continental slopes. This shift has already begun in those regions (such

as northern Europe) that are capable of building and equipping larger and more complex fishing vessels. Since we are just beginning to exploit this new ecosystem, it would be of great value, in order to prevent the mistakes of the past, to design pro-

grammes for sustainable fisheries, based on a solid knowledge pool. The aim of the present study was to characterise and compare the structure of the deep-sea continental slope ichthyofauna off the Algarve coast (Portugal).

In Portugal, deep-sea fish have limited economic value, and are landed mostly as bycatch of crustacean trawl fisheries, especially those targeting the Norway lobster *Nephrops norvegicus* (L., 1758) and the rose shrimp *Parapenaeus longirostris* (Lucas, 1846) (Gordon *et al.*, 2001). The major exception is the mesopelagic black scabbard *Aphanopus carbo*, Lowe, 1839, caught with long lines off the Madeira Islands (where there are also *Beryx* spp. fisheries) and Sesimbra, on the Portuguese mainland. In the Azores archipelago, this fishery has been introduced recently, and has already surpassed in landings the very important tuna fleet. On the mainland, landings of continental slope fishes remain of low economic importance. The most important captures belong to the blue whiting *Micromesistius poutasou*, especially in Matosinhos, northern Portugal, and elasmobranchs, such as dogfishes, with moderate landings all along the coast. Other species with interesting potential for human consumption, including the silver roughy *Hoplostethus mediterraneus mediterraneus* (Figueiredo, Figueiredo and Correia, 1996), have no economical value.

Despite increasing research on deep-sea fisheries, it remains to be evaluated to what extent the present resource management policies are, in fact, efficient. For instance, the important orange roughy *Hoplostethus atlanticus* Collett, 1889, fishery in New Zealand and Australia has been regulated in the near past by regulatory practices which, although considered effective, have not, in fact, produced satisfactory results, even when quotas were maintained at very conservative levels (Clark, 2001). Koslow and Tuck (2001) suggest it might be due to episodic rather than stochastic (as is most common) recruitment periods. In addition, there are also problems concerning biological aspects of deep-sea benthos-associated teleosts. Many species have been found that have low growths and late maturation ages (Koslow, 1996; Allain and Lorange, 2000), which represent a serious problem insofar as stock management is concerned –and this matter is worsened by other difficulties involving age validation in deep-sea fish (Allain and Lorange, 2000). Yet another problem concerns discards, which should not be disregarded when as-

sessing stocks of species that have slow growths (thus reaching commercial size at late ages), and for which adults and juveniles coexist on the same grounds (Lorange, Dupouy and Allain, 2001). These examples illustrate how little we know about deep-sea ecosystems, and that the more conventional management models may not be suitable for this kind of marine resource.

The present paper intends to contribute to the study of a specific ecosystem in Portuguese deep waters by characterising and comparing the ichthyological structure of the continental slope using diversity and biomass values.

MATERIALS AND METHODS

Our data were obtained during the deep-ocean resources campaigns of the Ipimar (Portuguese Institute for Marine Research) aboard the NI *Noruega* during August/September 1990-1992 and April/May 1992 and 1994 (published data from Figueiredo, Figueiredo and Moura, 1994).

The capture procedure consisted of 1-h trawls along the continental slope, using a crustaceans net with a 20 mm-mesh cod end. The speed of the trawls was maintained constant at 3 knots. Considering the area swept in each trawl, the final data are expressed in densities, or, more accurately in biomass, expressed in kg/nm² (kilograms per square nautical mile). The depth of the trawls ranged from 100 to 900 m, and the final biomass value, for each species and sector, was obtained by simple mean when multiple stations were prospected (station co-ordinates have not been published). In the present work, we used only the data concerning the strata (depth intervals) between depths 400-500 m, 500-600 m, 600-700 m, and 800-900 m, according to the ICES deep-ocean resources definition.

The biomass information gathered concerns seven chondrichthyan species, six of which are elasmobranchs (Selachii), plus *Chimaera monstrosa* (Chimaeridae, Chimaeriformes), and ten species of teleosts. The studied species are summarised in table I. The data from Figueiredo, Figueiredo and Moura (1994) do not offer any capture information regarding other fish species. For simplicity's sake, species were given codes, according to the standard Ipimar procedures. We also grouped the original trawling stations into two major sectors: leeward and windward, to which we attributed the

Table I. Species description

	Species	Code	Common name
Teleosts	<i>Merluccius merluccius</i> (L., 1758)	HKE	Hake
	<i>Helicolenus dactylopterus</i> Delaroche, 1809	BRF	Bluemouth, rockfish
	<i>Phycis blennoides</i> (Brünnich, 1768)	CBF	Greater forkbeard
	<i>Conger conger</i> (L., 1758)	COE	Conger eel
	<i>Lophius budegassa</i> Spinola, 1807	BUD	Blackbelly anglerfish
	<i>Hoplostethus mediterraneus</i> Cuvier, 1829	HOE	Rosy soldier fish
	<i>Trachyrhynchus trachyrhynchus</i>	TRT	Longsnout grenadier
	<i>Malacocephalus laevis</i> (Lowe, 1843)	MAA	Softhead grenadier
	<i>Nezumia sclerorhynchus</i> (Valenciennes, 1838)	NEL	Roughtip grenadier
	<i>Micromesistius poutassou</i> (Risso, 1826)	WHB	Blue whiting
Condriactians	<i>Galeus melanostomus</i> Rafinesque, 1810	SHO	Blackmouth dogfish
	<i>Scyliorhinus canicula</i> (L., 1758)	SCA	Small spotted dogfish
	<i>Deania calceus</i>	DEA	Birdbeak dogfish
	<i>Dalatias licha</i> (Bonnaterre, 1788)	DAL	Kitefin shark
	<i>Chimaera monstrosa</i> L., 1758	CHM	Rabbitfish
	<i>Etmopterus spinax</i> (L., 1758)	ETS	Velvet belly
	<i>Centrophorus granulosus</i> (Blach et Schneider, 1801)	GUP	Gulper shark

codes SOT and BRL, respectively (figure 1), with 37 stations allocated to each. The species studied are bottom-dwellers over the continental slope, with the exception of the blue whiting *Micromesistius poutassou*, a mesopelagic that frequently exhibits benthopelagic behaviour. All of these species possess present or potential economical value. Differing from the rest of the species are the hake *Merluccius merluccius*, the blackbelly anglerfish *Lophius budegassa*, and the conger eel *Conger conger*, which can be found over the continental shelf and are not, thus, typical deep-sea species.

We transformed our data transformed with the formula $\log_{10}(\text{biomass} + 1)$ in order to minimise the effect of the most discrepant values. Data management and processing were performed with Microsoft Excel and Statsoft Statistica software packages.

We divided the analysis into seven steps. The first consisted of basic data management and transformation. Then followed descriptive analysis (with the specific richness being based on the number of species found in each sector), cluster analysis (using Euclidean distances for station clustering and Bray-Curtis distances for species), discriminant analysis, and principal component analysis. In order to obtain a distance matrix between species, we used the Bray-Curtis dissimilarities index –for refe-

rences on this procedure see Bray and Curtis (1957) and Beals (1984). We performed the final analysis on the differences between both sectors and created, as a descriptive procedure, 3D graphics for the most relevant species distribution using polynomial models. The higher the polynomial order and lower the stiffness, the closer the model is to the raw data. For this specific project, we used zero stiffness and a fifth order polynomial model. The data input also consisted of logarithmically transformed data, in order to minimise high discrepancies, thus obtaining a smoother, easier surface to analyse.

RESULTS

We drew up basic statistic graphs in order to have a good perspective on the species diversity (specific richness) and total biomass for sampling seasons combined in both sectors, according to depth intervals and sampling seasons (figure 2).

Cluster analysis enabled us to build distance matrices between the stations, having again combined the data from all sampling seasons (figure 3). Our results showed that it was possible to group densities by depth intervals; however, it was not possible to clearly group species densities by sampling seasons. Using the Bray-Curtis index, we obtained

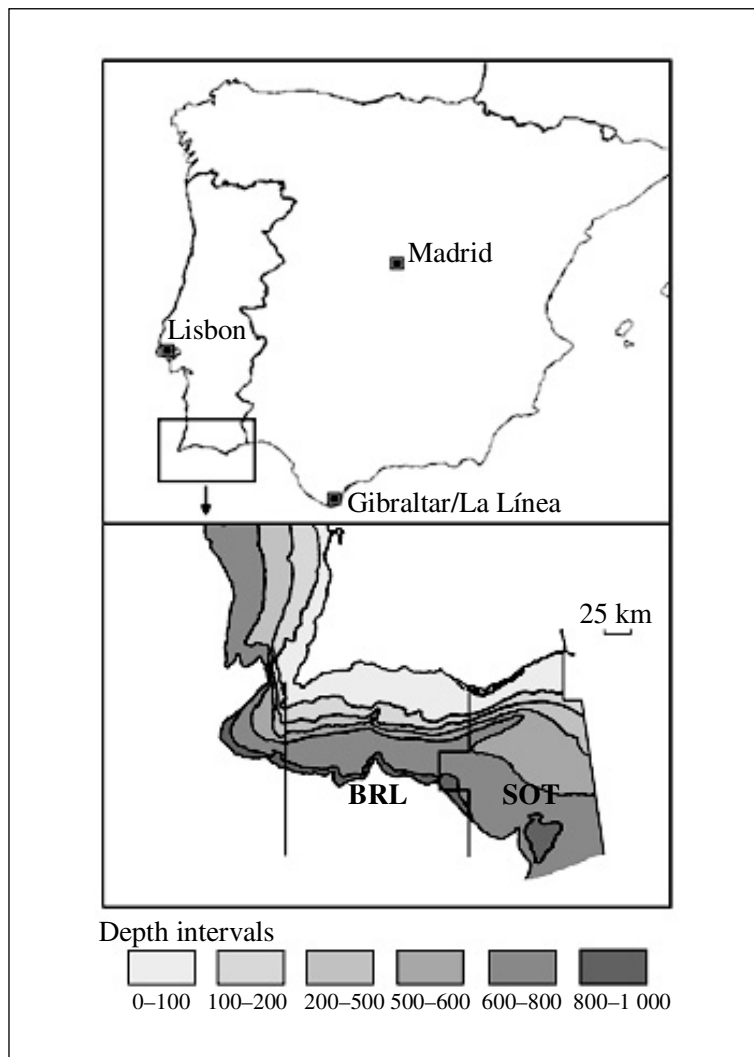


Figure 1. Sectors location map

classification trees between species' biomasses (figure 4).

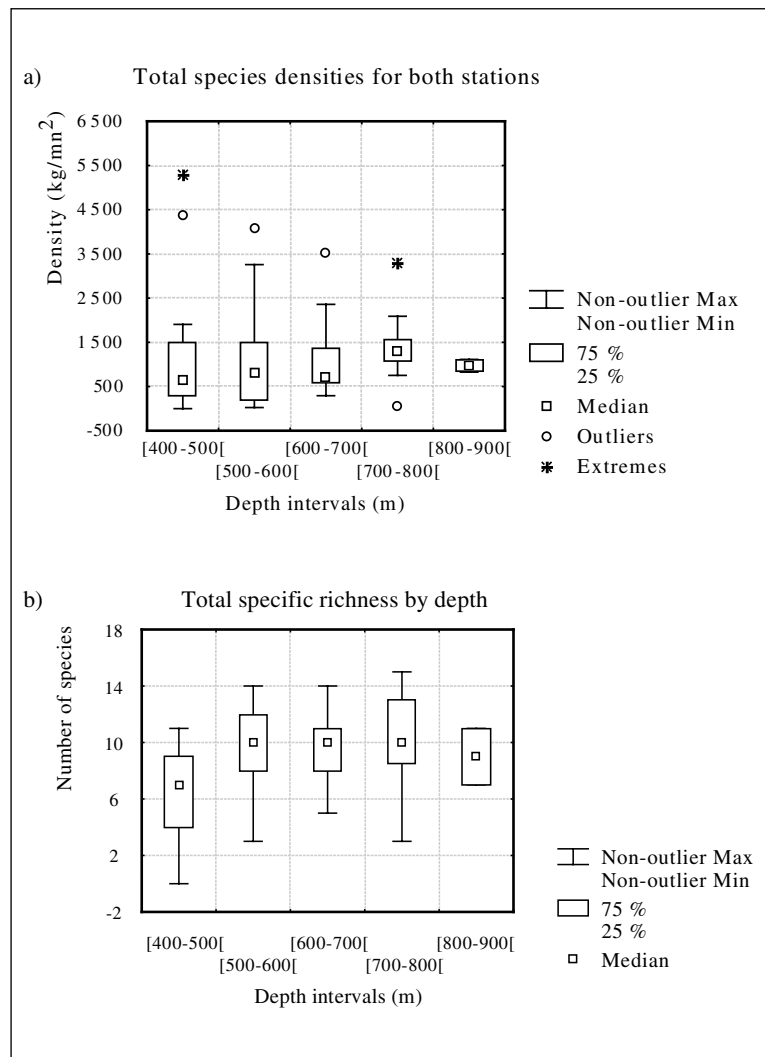
Species clustering (UPGMA) using the Bray-Curtis dissimilarities index gave rise to species differentiation according to their densities (total depths and years data). It is to be noted that the Bray-Curtis coefficient is frequently used with this type of data because it ignores cases in which the species are absent in both measures to be compared and enhances the species with little representation. For the Barlavento sector, three specific groups emerged (figure 4a). The first group contains the species GUP (see table I), isolated from others due to its comparatively low biomass values, followed by a second group containing the most harvested species (SCA, WHB, BUD, HKE), and a third group with the remaining species. However, in the Sotavento sector (figure 4b), the patterns between species densities are quite dissimilar. Two major groups can

be distinguished, with the species TRT, HOE, DEA, DAL and GUP having the lowest densities.

Results of discriminant analysis applied both to BRL and SOT yielded discriminant functions, which, according to Wilks's- λ criterion, differentiated depth intervals highly significantly ($p < 0.001$). Three and four discriminant functions were generated. However, only indices corresponding to the first two were analysed, since 91-92 % of initial variance were represented by them. Moreover, the 100 % correct assignments of all strata for BRL and SOT, excepting 500-600 m for SOT, indicated satisfactory discrimination between depth intervals. A plot of scores for the sampling stations combining the two sectors revealed a clear separation of depth groups (figure 5).

The standardised discriminant function coefficients enabled us to identify the most discriminating species among depth intervals. Therefore,

Figure 2. (a): box-and-whisker plot for total densities. (b): box-and-whisker plots on the specific richness per depth interval



CBF, MAA, DEA and HOE exhibited higher contrasting depth distributions for BRL and as for SOT, the principal discriminating species were NEL, DEA, DAL, CBF and ETS.

Application of discriminant analysis to geographic groups, in which sectors SOT and BRL were originally divided (figure 6), revealed ZET as the most divergent group (100 % correct classification), insofar as species densities along temporal and bathymetric scales were concerned. Densities of GUP and BRF were the most determinant for that separation. These results were obtained within the original four sectors considered by the Ipimar: sector BRL including ALB (off Albufeira) and SAG (off Sagres) and SOT including TAV (off Tavira) and ZET, south of TAV (figure 7).

Principal Component Analysis (PCA-Varimax rotation) applied to BRL retrieved two major functions (F1, eigenvalue: 5.62; F2, eigenvalue: 2.09),

which explained 45.33 % of the original variability. The species COE (0.89), SHO (0.79), CHM (0.79) and NEL (0.76) were the main contributors for F1, and MAA (0.75) for F2, and thus, are considered the species with the highest discrimination capability for strata faunal patterns.

For sector Sotavento, PCA derived two functions (F1, eigenvalue: 5.06; F2, eigenvalue: 2.90) which, together, explain 46.85 % of the original variability. GUP (0.89), DAL (0.72) and DEA (0.70) occurred as the main contributors for F1, and BRF (0.83), CHM (0.82) and SHO (0.77) for F2.

The depth interval between 700 and 800 m is the most consistent (figure 8), with increased densities of the F1 contributor species, GUP, DEA and DAL. The remaining intervals do not show distinct patterns. Nonetheless, the 400-500 m and 500-600 m depth intervals present consistent results, with an opposite trend to the aforesaid, regarding F1 spe-

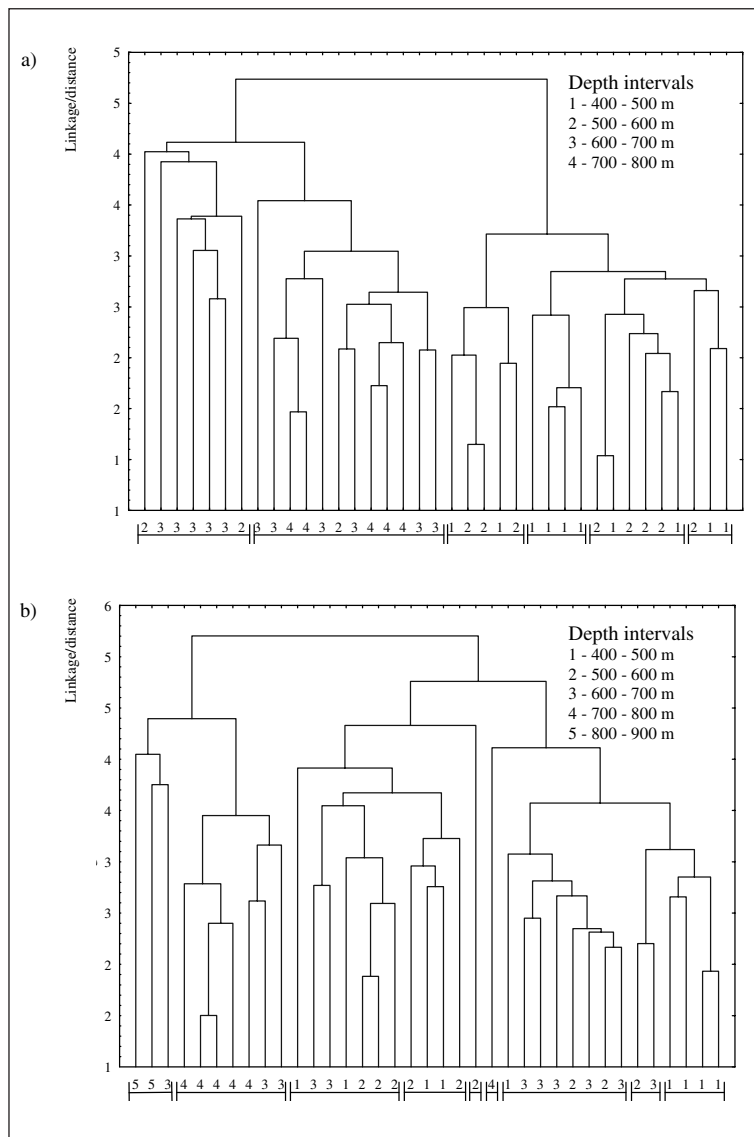


Figure 3. (a): unweighted pair-group average Euclidean distances for sector BRL (total stations/years clustering). (b): unweighted pair-group average Euclidean distances for sector SOT (total stations/years clustering)

cies biomass. The remaining depth interval (600-700 m) is very heterogeneous regarding biomasses; however, SOT has a narrower span in this depth interval than BRL. The 3D models presented on figure 9 show the biomass distribution of species DEA, DAL and GUP by depth and its variation within a timeline, being these species those that contribute the most to the differentiation between the sectors and slope habitats of depths greater than 700 m.

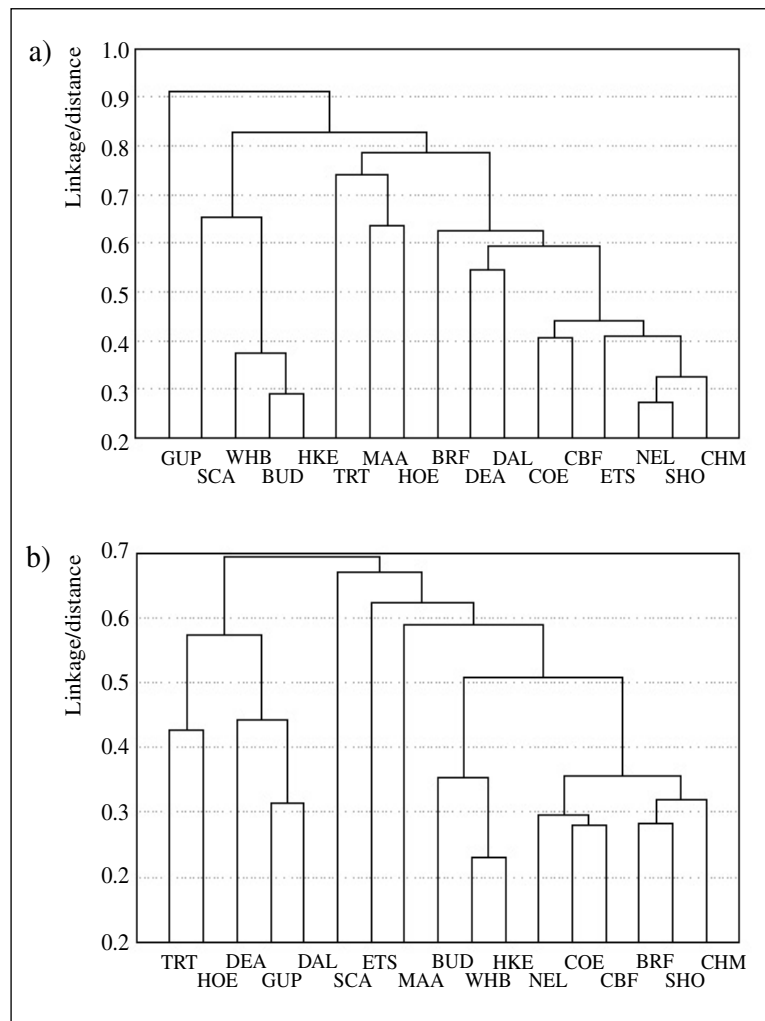
DISCUSSION

It seems clear that even at 100 m depth intervals there is a clear distinction within the continental

slope-associated fish assemblages with regard to depth and sectors. Low temporal changes may indicate that slope habitats are less affected by the common seasonal factors, either meteorological or oceanographic, that usually influence shallow water habitats. Nevertheless, the temporal range of this study is insufficient to draw conclusions on this matter, or to assess the actual impact of fisheries on benthos-associated fish assemblages.

An important conclusion concerns the division of the continental slope habitat. According to our results, there seems to be a separation between depths above and below 700 m, due to an increase in the abundance of commonly deeper-living elasmobranch species like *Deania calceus*, *Dalatias licha*

Figure 4. Joining trees based on Bray-Curtis dissimilarities coefficient. (a): sector BRL; (b): sector SOT



and *Centrophorus granulosus*. The increase in species richness of the depth interval between 700-800 m may also explain this fact, since it is likely to be a transitory interval, where species of both divisions can be found. It is noteworthy that, according to our results, there is a larger biomass in the upper depth intervals of the continental slope (from 400 and 600 m).

Some species appear together, with similar biomasses in both sectors, forming three conspicuous groups. One group comprises the species *M. pou-tassou*, *L. budegassa* and *M. merluccius*, the second *C. conger* and *Phycis blennoides* and the third *C. monstrosa* and *Galeus melanostomus*. The explanation for these patterns is most likely ecological; however, data on resources sharing by deep-sea fish are still scarce, and energy webs in such a food-poor environment are complicated. It should be noted that deep-sea bottom dwellers are thought to be opportunistic, ranging from active predation to scaven-

ging. Drazen, Buckley and Hoff (2001), for example, reported that two species of eastern Pacific macrourids (Macrouridae, Gadiformes) which hover around the same territory and are dominant on the upper continental slope, not only have a considerable degree of niche separation regarding preys, but also show different preferences from larger and smaller individuals. This differentiation, if it were found applicable to many other benthos-associated species, would explain, at least partially, how a considerable number of species can coexist without one becoming dominant over the other.

It is also important to note that subsector ZET is the most differentiated area in the study, generally characterised by higher biomasses of two species with considerable economical value: *C. granulosus* and *Helicolenus dactylopterus*. Further research in this area would be of great importance since, in the future, it might become a target of commercial fisheries.

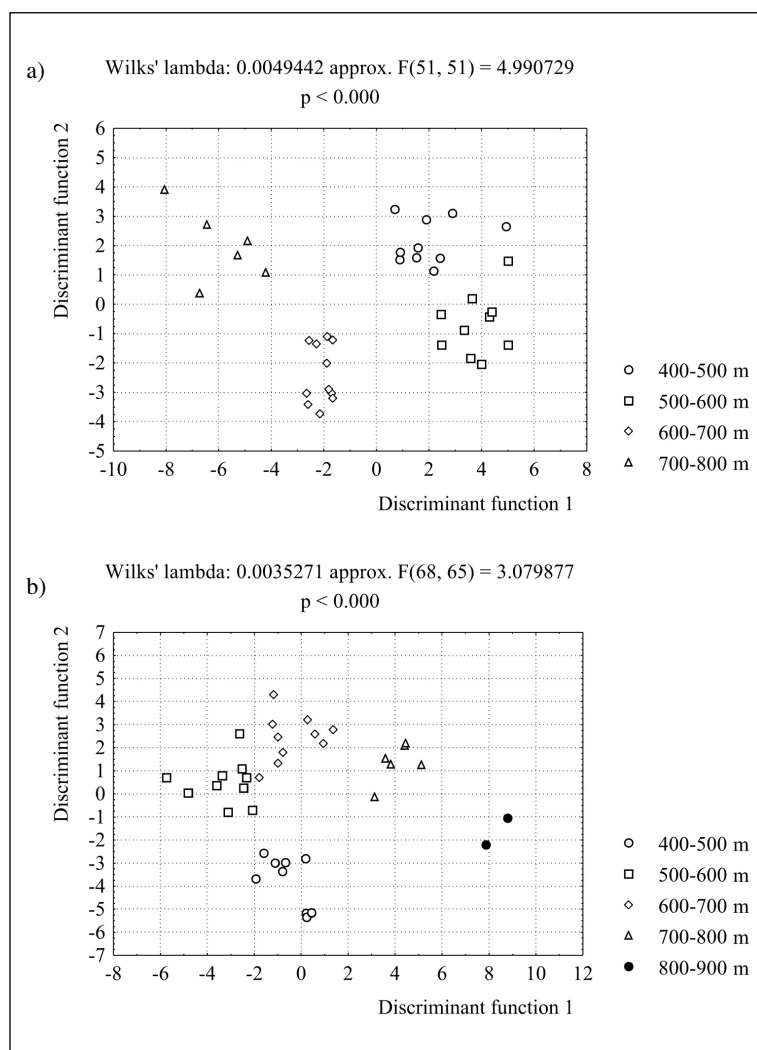


Figure 5. Discriminant analysis scatterplots by depth. (a): sector BRL; (b): Sector SOT

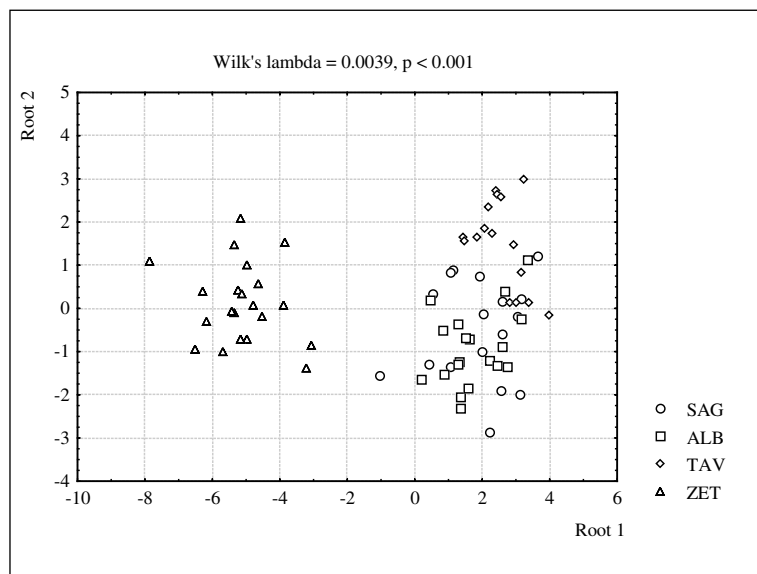


Figure 6. Discriminant analysis scatterplot according to species biomass for the subdivisions of sectors BRL and SOT

Figure 7. Subdivisions (subsectors) of BRL and SOT

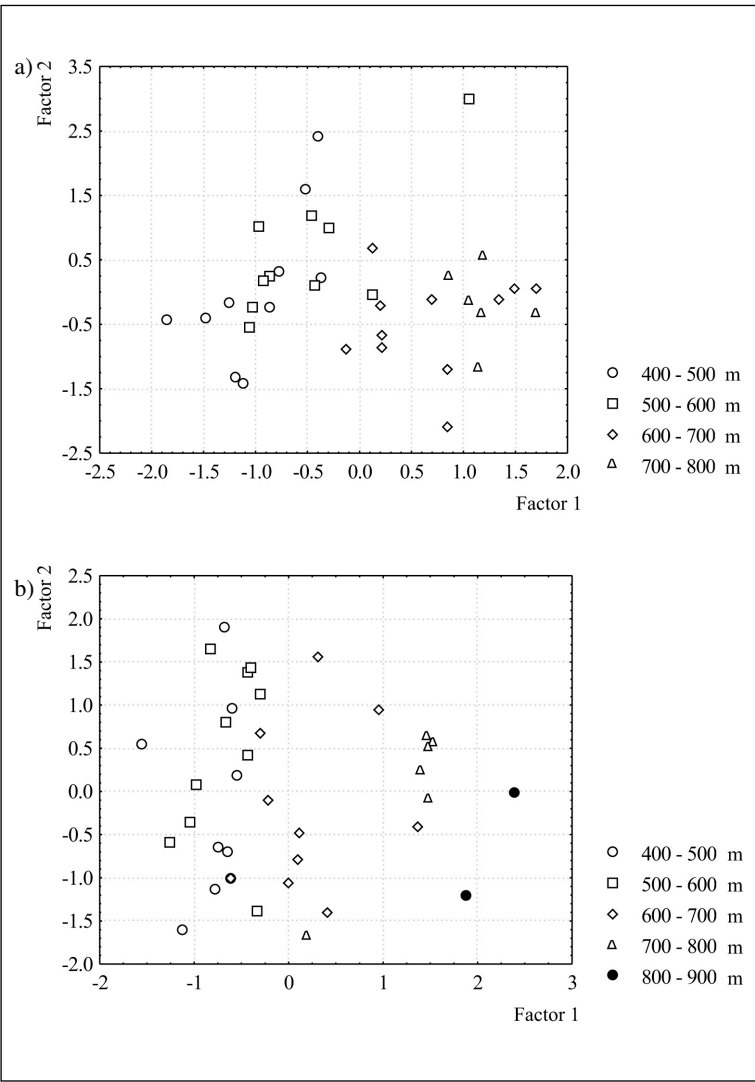
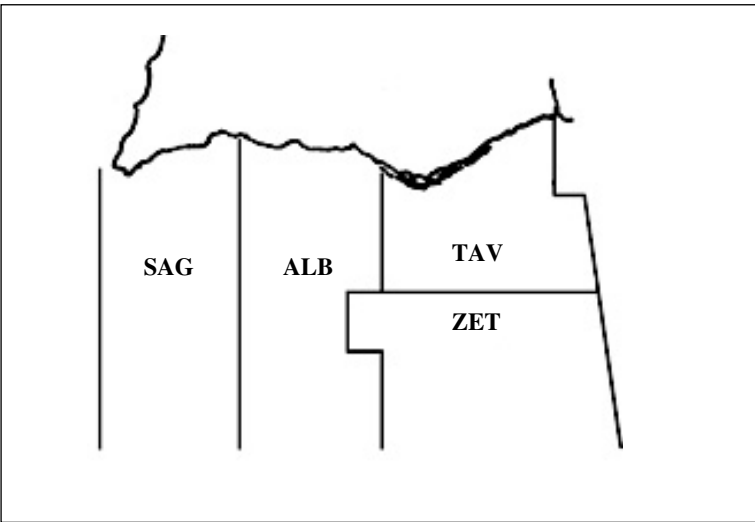


Figure 8. Principal component analysis results. (a): sector BRL; (b): sector SOT

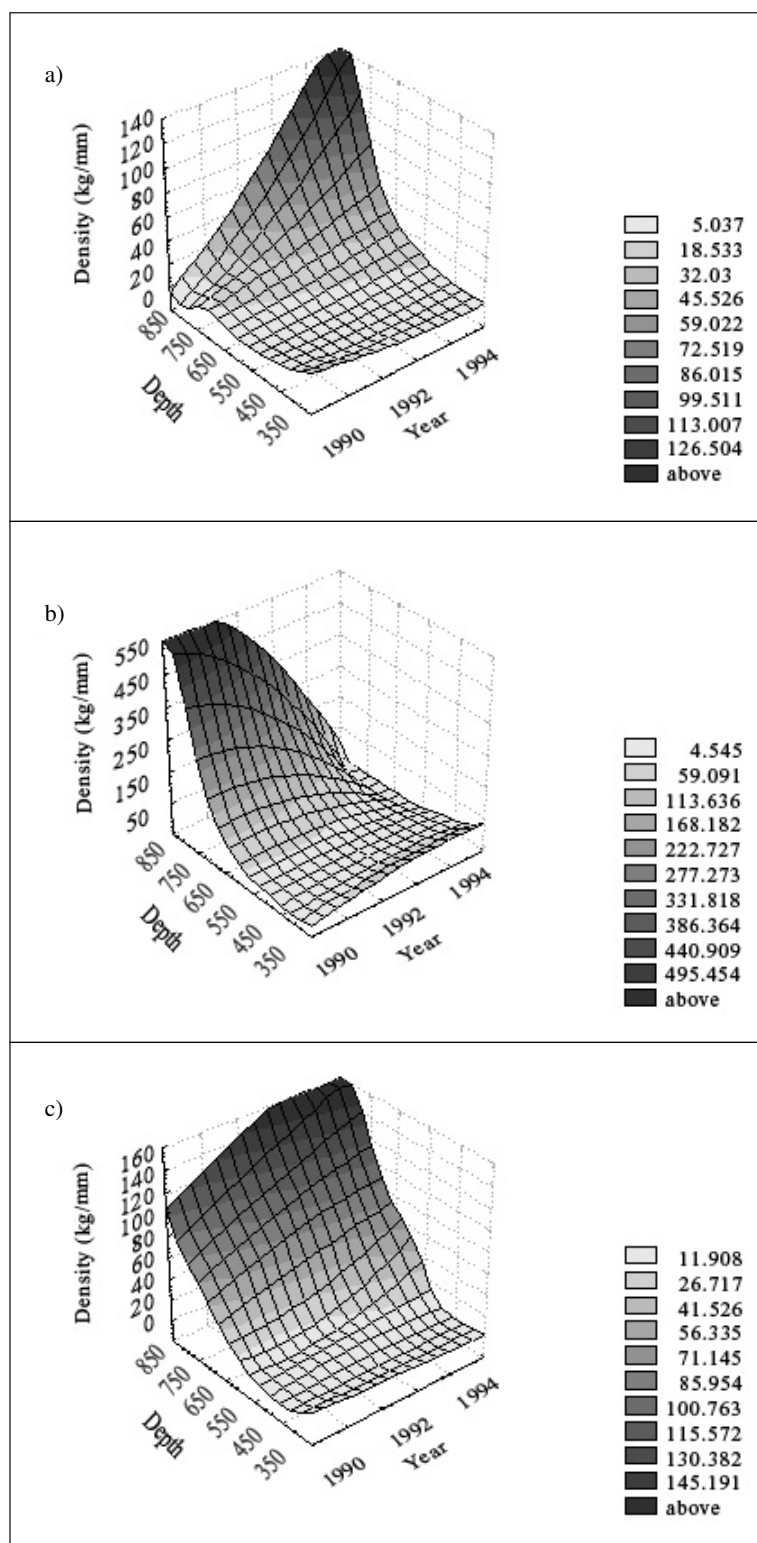


Figure 9. Three-dimensional biomass distribution graphs for the species. (a): *Deania calceus*; (b): *Dalatias licha*; and (c): *Centrophorus granulosus*

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REFERENCES

- Allain, V. and P. Lorance. 2000. Age estimation and growth of some deep-sea fish from the northeast Atlantic ocean. *Cybium* 24 (3): 7-16.
- Beals, E. W. 1984. Bray-Curtis ordination: an effective strategy for analysis of multivariate ecological data. *Advances in Ecological Research* 14: 1-55.
- Bray, J. R. and J. T. Curtis. 1957. An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs* 27: 325-349.
- Clark, M. 2001. Are deepwater fisheries sustainable? The example of orange roughy (*Hoplostethus atlanticus*) in New Zealand. *Fisheries Research* 51: 123-135.
- Drazen, J. C., T. W. Buckley. and G. R. Hoff. 2001. The feeding habits of slope dwelling fishes in the eastern north Pacific. *Deep-Sea Research I* (48): 909-935.
- Figueiredo, M. J., I. Figueiredo and O. Moura. 1994. *Peixes de profundidade da costa continental portuguesa*. Relatórios Científicos e Técnicos do IPIMAR. Lisbon: 85 pp.
- Figueiredo, M. J., I. Figueiredo and J. Correia. 1996. *Caracterização geral dos recursos de profundidade em estudo no IPIMAR*. Relatórios Científicos e Técnicos do IPIMAR. Lisbon: 50 pp.
- Gordon, J. D. M., O. A. Bergstad, I. E. Figueiredo and G. Menezes. 2001. The Deep-water Fisheries of the ICES Area. In: *Deep-sea Fisheries Symposium* (12-14 September, 2001. Varadero, Cuba). *NAFO SCR Doc.* 01/92: 16 pp.
- Koslow, J. A. 1996. Energetic and life-history patterns of deep-sea benthic, benthopelagic and sea-mount associated fish. In: *Annual International Symposium of the Fisheries Society of the British Isles* (1-5 July, 1996. Aberdeen, Scotland). *Journal of Fish Biology* suppl. A: 54-74.
- Koslow, J. A. and G. Tuck. 2001. The boom and burst of deep-sea fisheries: Why Haven't We Done Better? In: *Deep-sea Fisheries Symposium* (12-14 September, 2001. Varadero, Cuba). *NAFO SCR Doc.* 01/141: 10 pp.
- Lorance, P., H. Dupouy and V. Allain. 2001. Assessment of the roundnose grenadier (*Coryphaenoides rupestris*) stock in the Rockall Trough and neighbouring areas (ICES sub-areas V-VII). *Fisheries Research* 51: 151-163.